

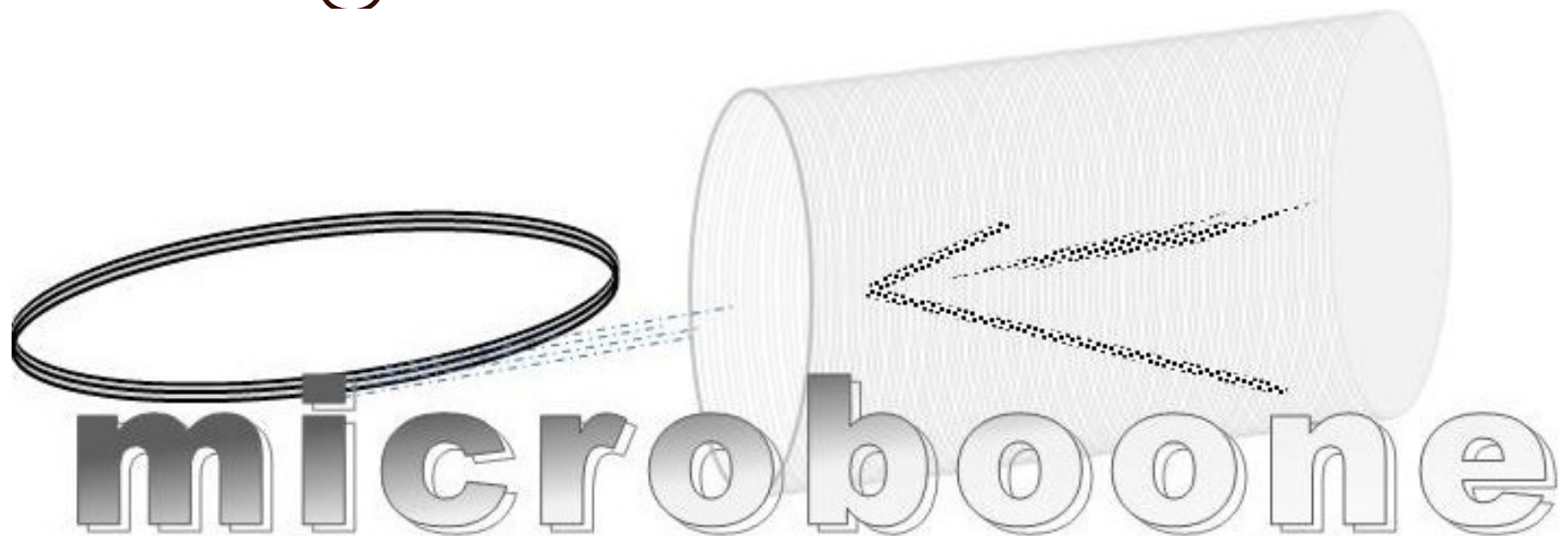
PMT Triggering and Readout for the MicroBooNE Experiment

David Kaleko (Columbia University)

for the MicroBooNE Collaboration

May 31, 2013

LIDINE @ FNAL



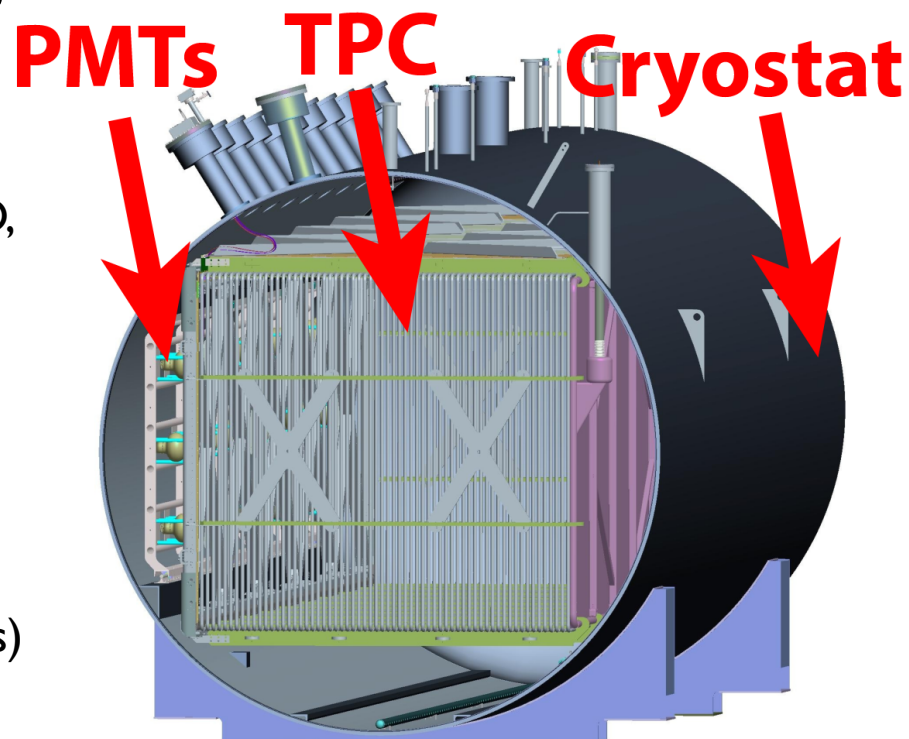


Outline

- General MicroBooNE
- Physics PMTs can Investigate
- PMT Electronics
- PMT Triggering

General MicroBooNE

- Liquid Argon TPC: 170ton LAr, 86ton active.
- 32 cryogenic PMTs: triggering and timing information.
 - Also reconstruction, cosmic ID, etc.
- TPC:
 - 3mm wire spacing
 - 2.5m drift (1.6ms)
 - 500V/cm
 - 3 wire readout planes (Y, U, V)
 - **8256 channels** (cold preamps)
- Located *on surface*: ~5kHz cosmics (5-8 per 1.6ms drift time)



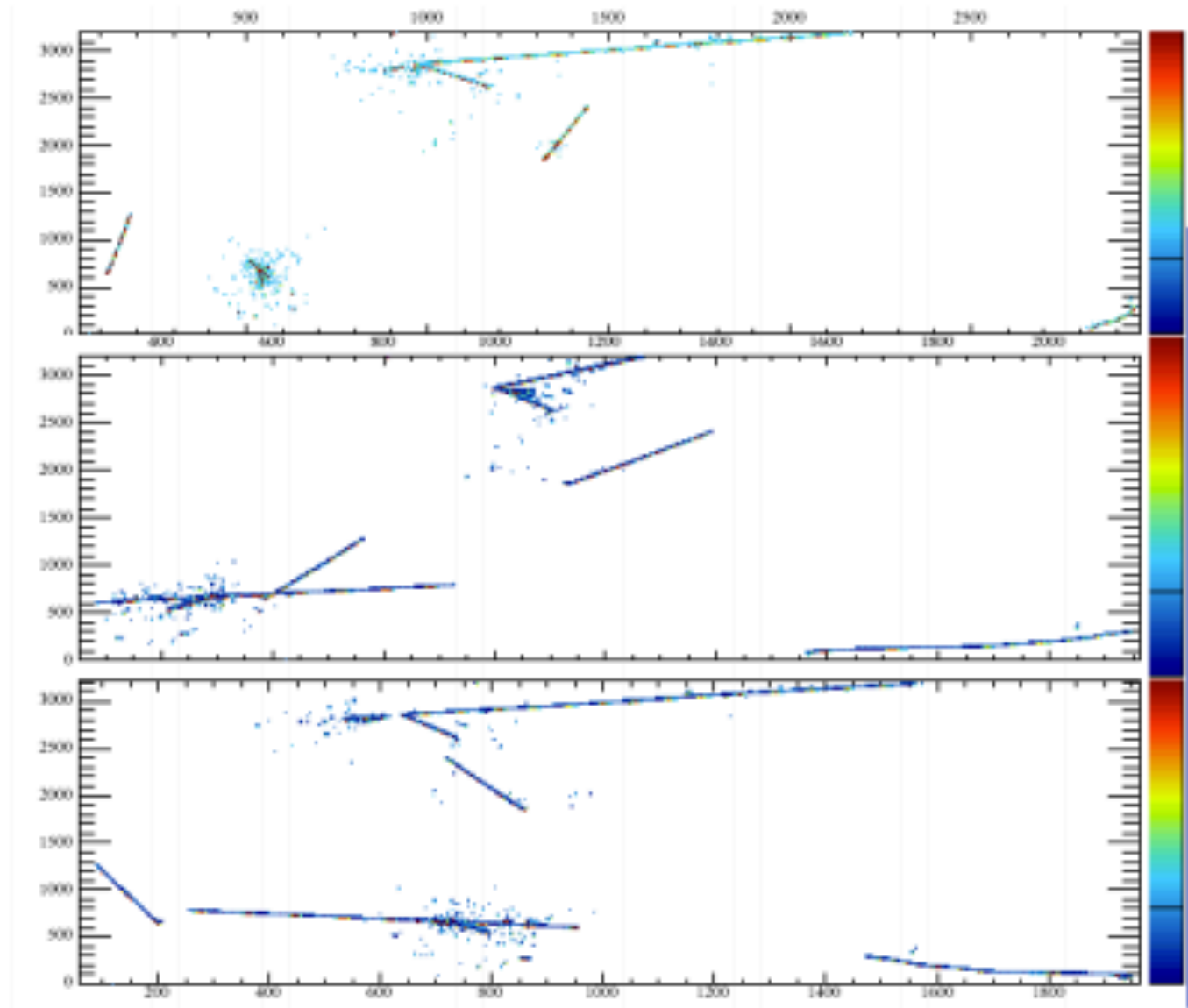


MicroBooNE Optical Detection

- See talk by Teppei immediately preceding this one.

Physics with PMTs

- Physics drives triggering and readout design
- PMT triggering and readout designed for various purposes
 - **Primary goal: isolate clean sample of neutrino interactions (PMT Trigger)**

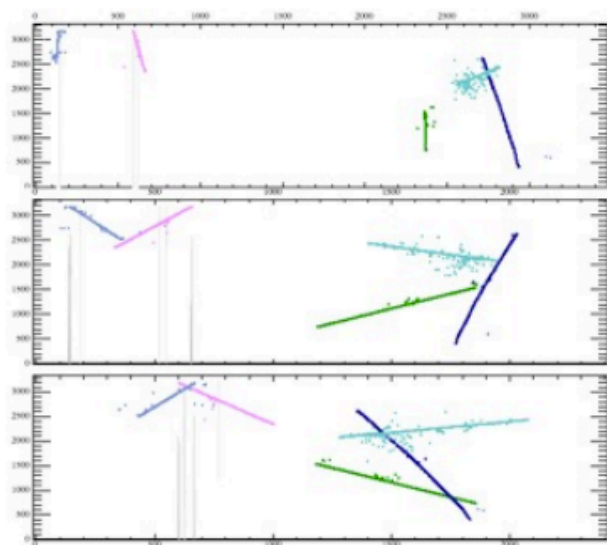


Physics with PMTs

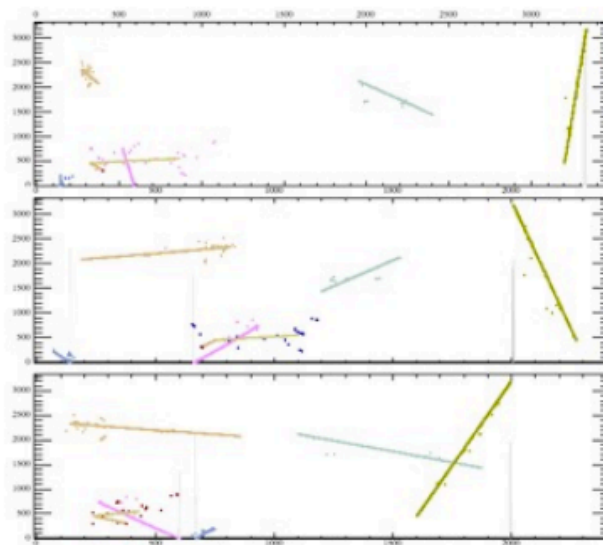
- Physics drives triggering and readout design
- PMT triggering and readout designed for various purposes
 - **Primary goal: isolate sample of neutrino interactions (PMT Trigger)**
 - Multiple components of scintillation light
 - Prompt, late scintillation
 - Prompt-to-late-light ratio for PID
 - Michel Electrons
 - Tagging Cosmics, PMT calibration
 - Low energy events (Supernova?) possibly below TPC reconstruction abilities

Tagging Cosmics

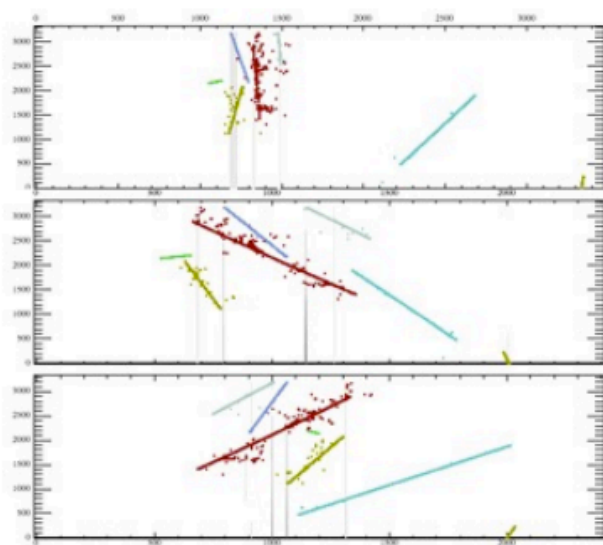
- ~Tens of cosmics in average 4.8ms TPC readout window
 - Need to reject these!
- Flash Finder (see Teppei's talk) helps isolate events in time with beam gate window
- Cosmics useful for calibrating PMTs
- Cosmic immediately before beam gate window can have late scintillation light arriving in the beam gate window



Pre-Spill



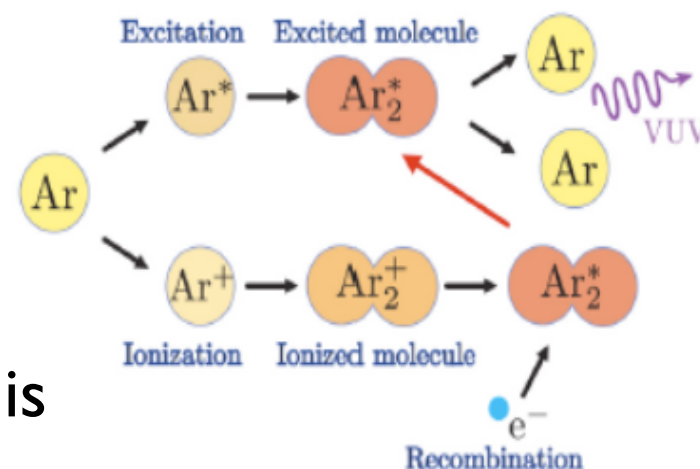
In-Spill



Post-Spill

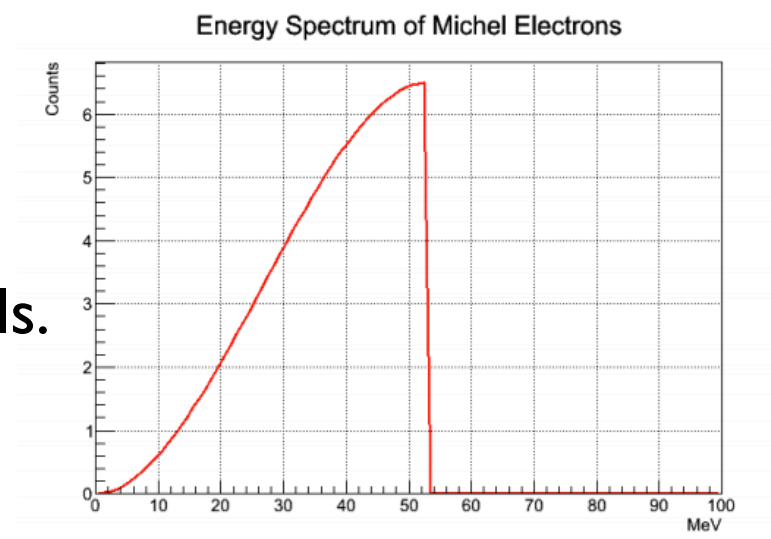
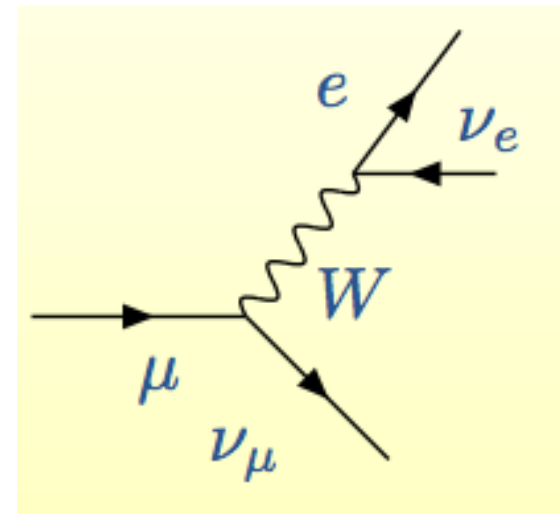
Late Light Scintillation

- Excited or ionized Ar atom may combine with ground state Ar atom to form excimer
 - This decays back into two GS atoms
 - Decay time depends on singlet or triplet state of excimer
- Prompt (singlet)
 - ~6nanosecond lifetime
- Late (triplet)
 - ~1.6microsecond lifetime
- Prompt-to-late light ratio is function of dE/dx (PID!)
- Need to make PMT readout accommodate for seeing this



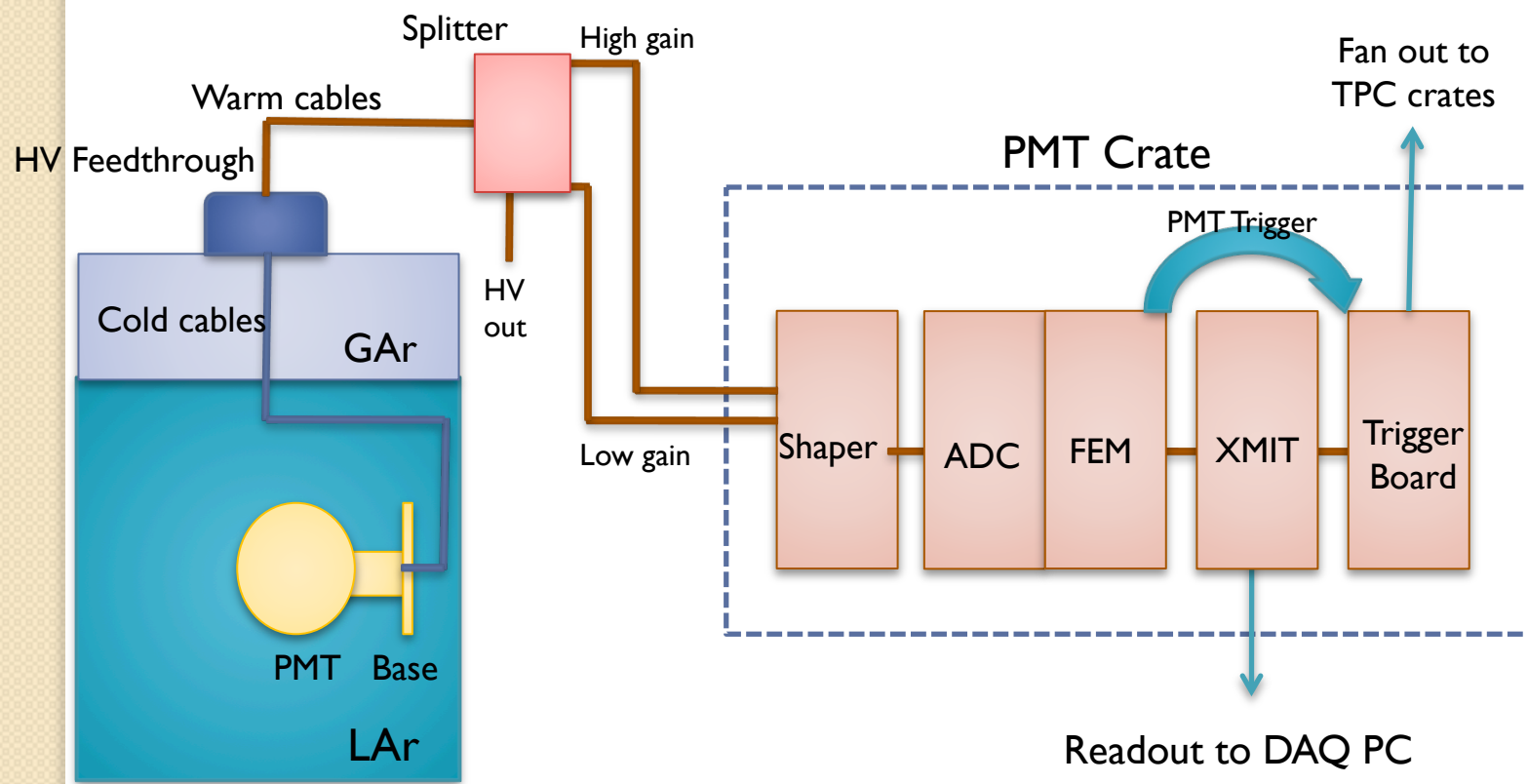
Michel Electrons

- Mu lifetime of 2.2μ seconds
- Michel electron distribution useful for:
 - Identifying a final state particle as muon
 - PMT calibration (QE tube-to-tube)
 - Calibrate light yield as function of position in detector
- CCPI+ channel has two muons: possibly two Michels.



PMT Electronics

- Includes signal shaper boards, PMT feedthrough, HV/ signal splitters, and a trigger board
- High gain vs. low gain extends dynamic range of ADC



PMT Electronics

- 64MHz (16ns) digitization
- Unipolar shaper
 - 60ns shaped rise time
 - 2-3 digitized samples on rising edge
 - Allows for accurate event start time determination
- FPGA on FEM responsible for generating PMT triggers



Shaped 25mV 25ns negative square pulse (differentially driven)



PMT Readout Structure

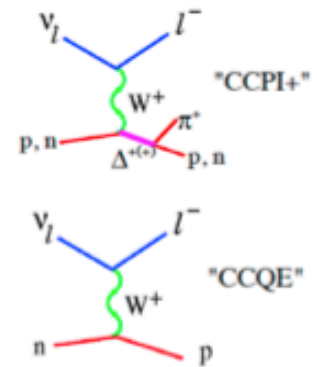
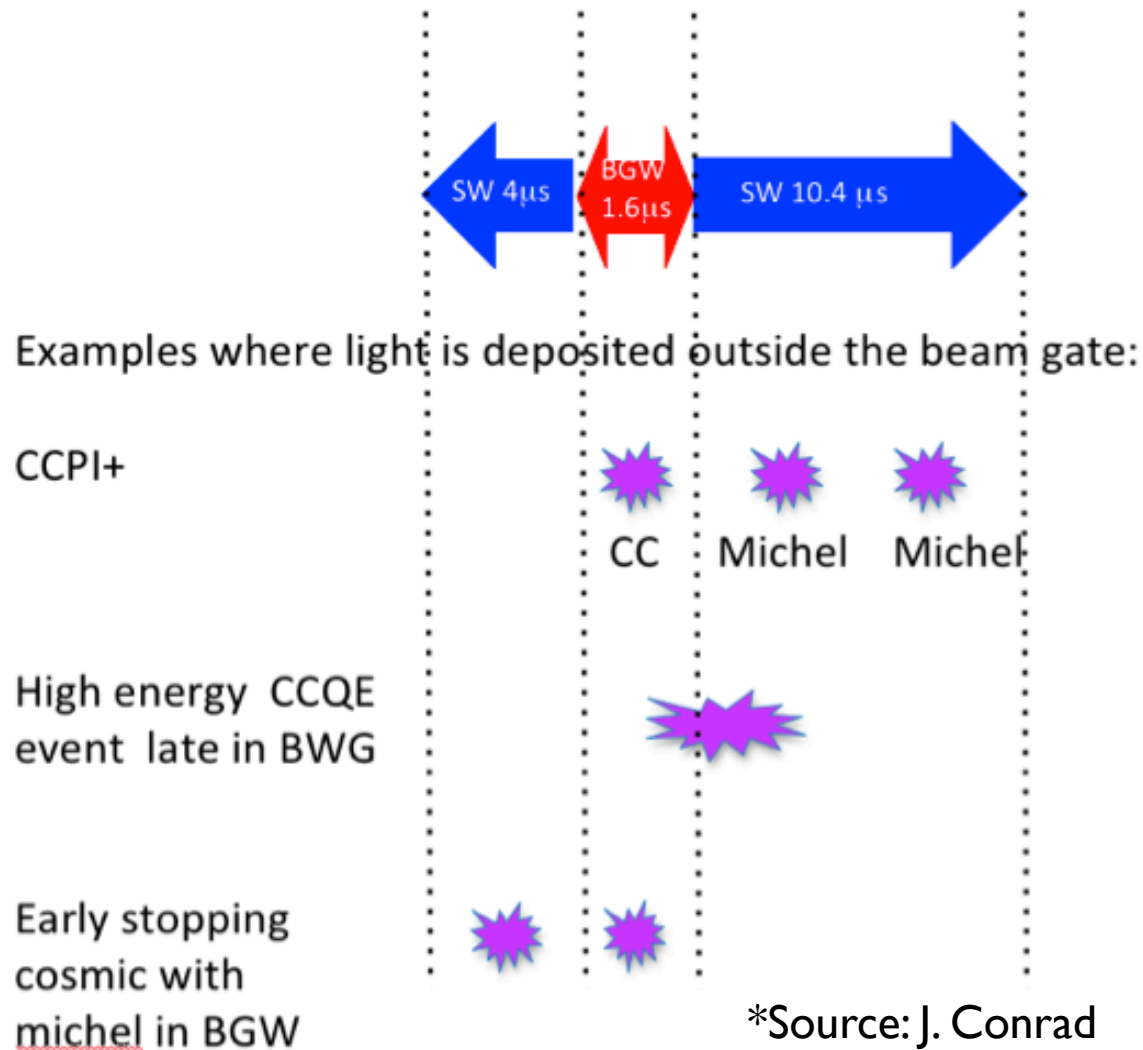
- We want to measure:
 - Sufficient information to identify sample of beam neutrino interactions
 - Timing of different background cosmics
 - Position of cosmics in detector
 - Prompt and late light
 - Michel electrons from beam
- All while having a manageable data rate
- Here's how we do it:

Readout structure

- Previous slides indicate that just reading out only beam gate window (BGW) is insufficient.
- Reading out 24/7 is unrealistic data volume
 - Need to read out a window surrounding BGW, “surrounding window” (SW)
 - 1500 samples, always read out
 - Need to read out small windows surrounding cosmoics outside of BGW, inside of 4.8ms TPC readout window (TPCW)
 - Possible readout durations outside of all other windows (OUTW)



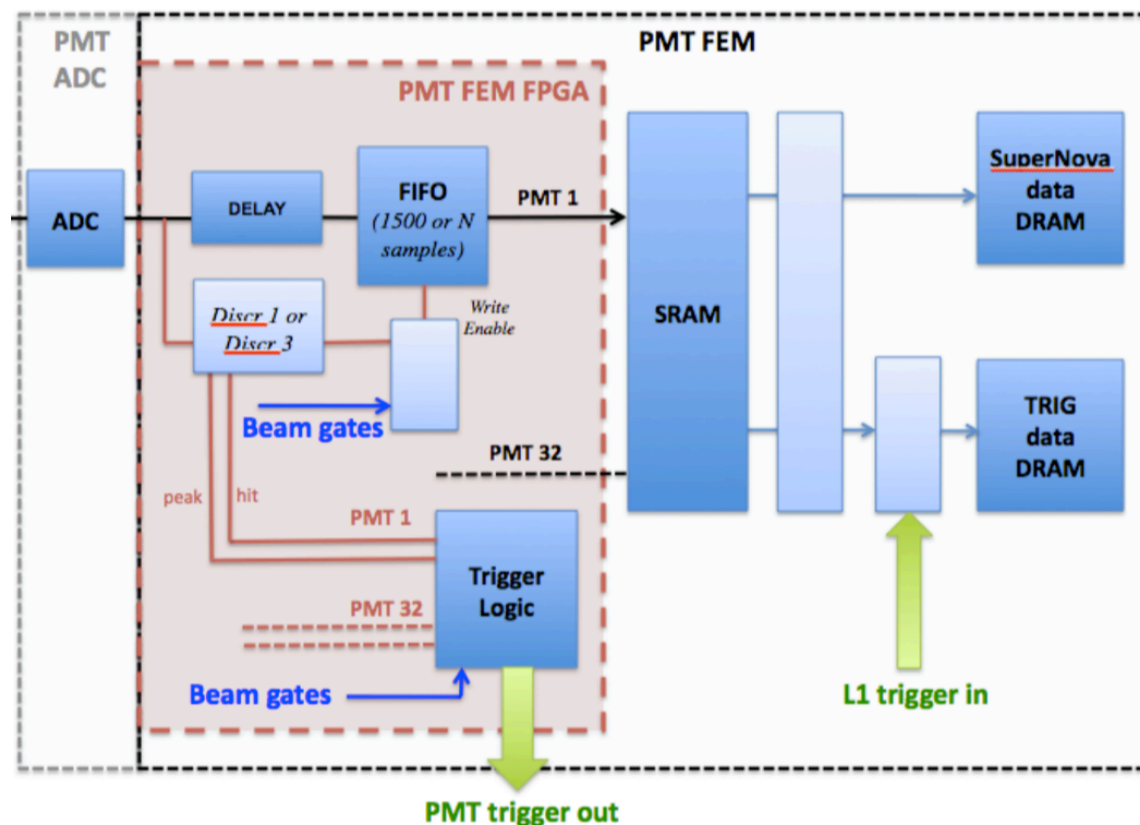
Why We Need “Surrounding Window”



*Source: J. Conrad

Triggering with PMTs

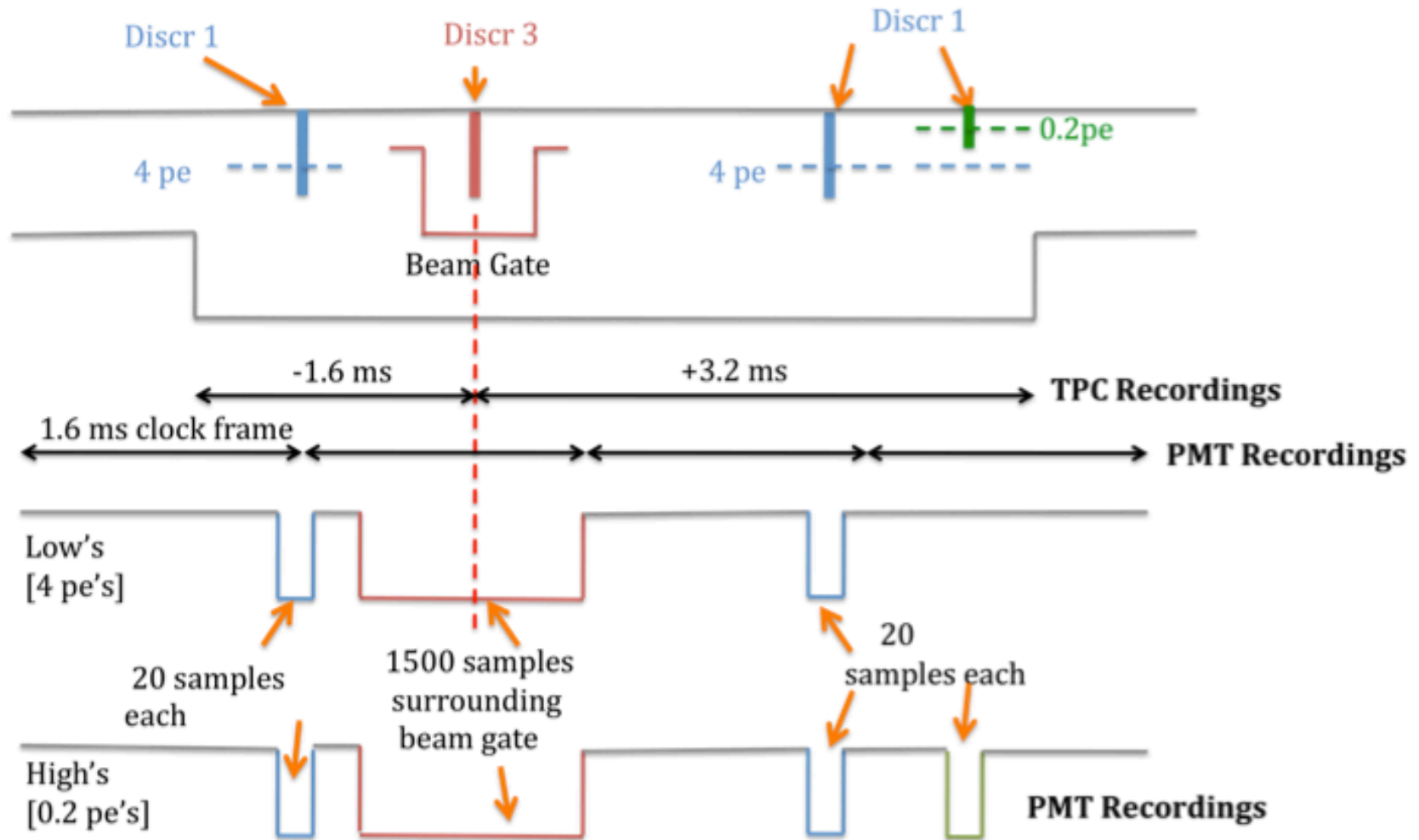
- Threshold/discriminator/timing conditions implemented in FPGA on PMT Front End Module.
 - Include pulse amplitude on single PMTs, summed coincidences on multiple PMTs, delayed coincidences (Michel electrons).



Conditions for PMT Triggers

- Discriminator levels 0, 1, 3
 - Low-threshold “Discr0” allows good timing
 - Low-threshold “Discr0” precondition for higher threshold “Discr1” outside of BGW (tagging cosmics)
 - Low-threshold “Discr0” precondition for higher threshold “Discr3” inside of BGW (beam events)
- Discriminators have associated dead-time and pre-count requirements to reduce triggering on noise and after-pulses
- All triggering on high-gain channel (currently)
- *All parameters configurable at run-time.*

PMT recordings during Beam events



Data Volume Reduction with PMTs

- Readout with no PMT requirement:
 - 1/125 BNB events read out have cosmic in gate
 - **1/2500** BNB events read out have neutrino event (2e12ppp)
- Readout based on PMT trigger:
 - Almost all events read out have cosmic in gate
 - **1/20** BNB events read out have neutrino event



Types of Triggers Available (OR'd)

- Beam event trigger
 - Beam PMT trigger in coincidence w/ beam gate
- Cosmic PMT trigger
- External trigger
- DAQ-issued calibration trigger
- Random trigger



Conclusion

- PMTs capable of studying important/interesting physics, and readout structure is designed accordingly
- PMT system produces trigger signals for entire readout and DAQ system
- All triggering/readout parameters configurable at run-time
- Data taking starts beginning of 2014!

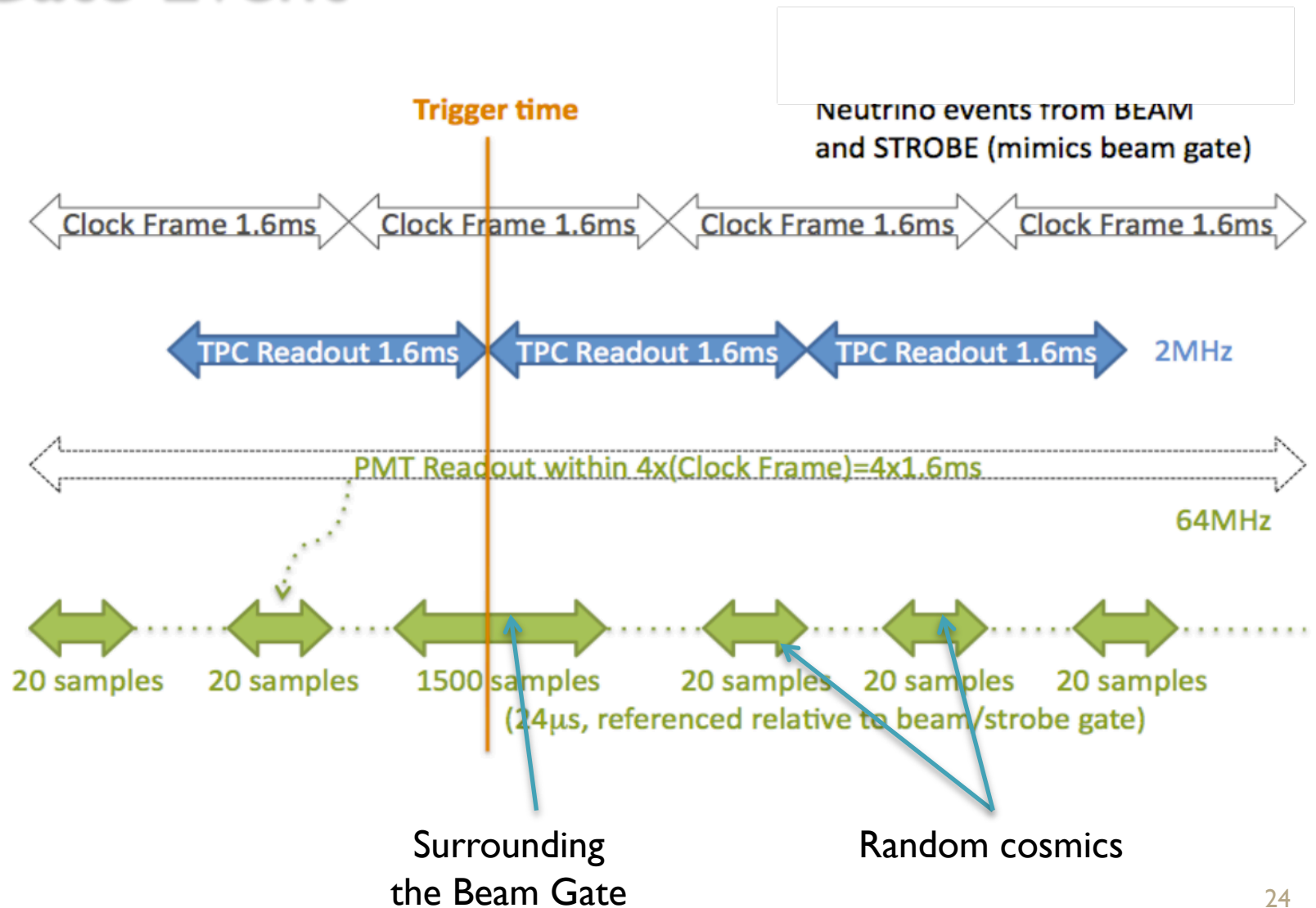
THE END





Backup Slides

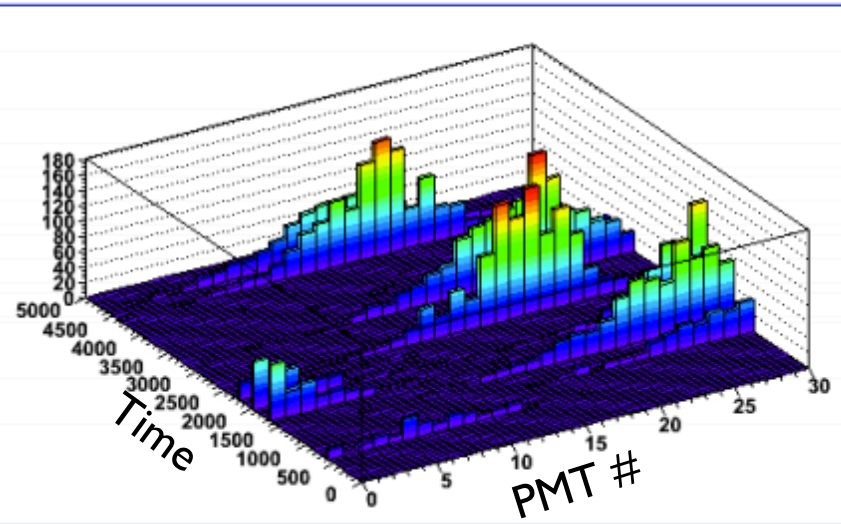
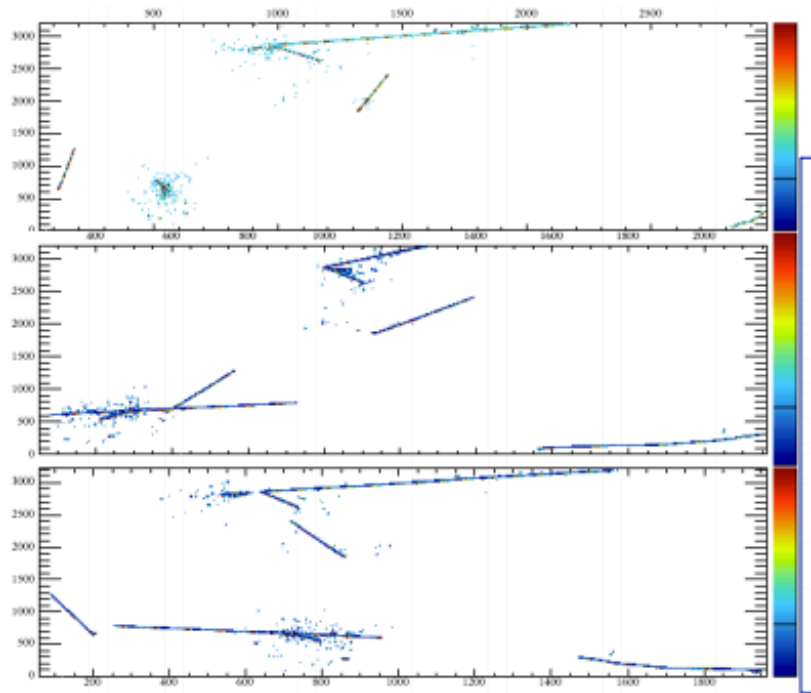
TPC + PMT Readout Data For A Beam Gate Event



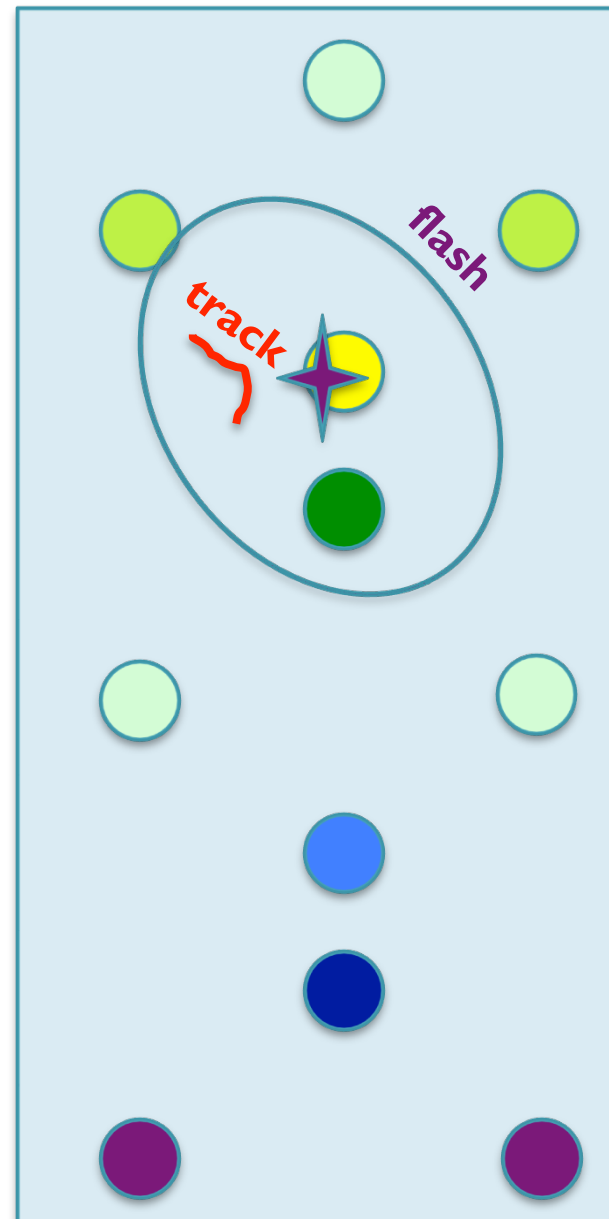


Flash Finder

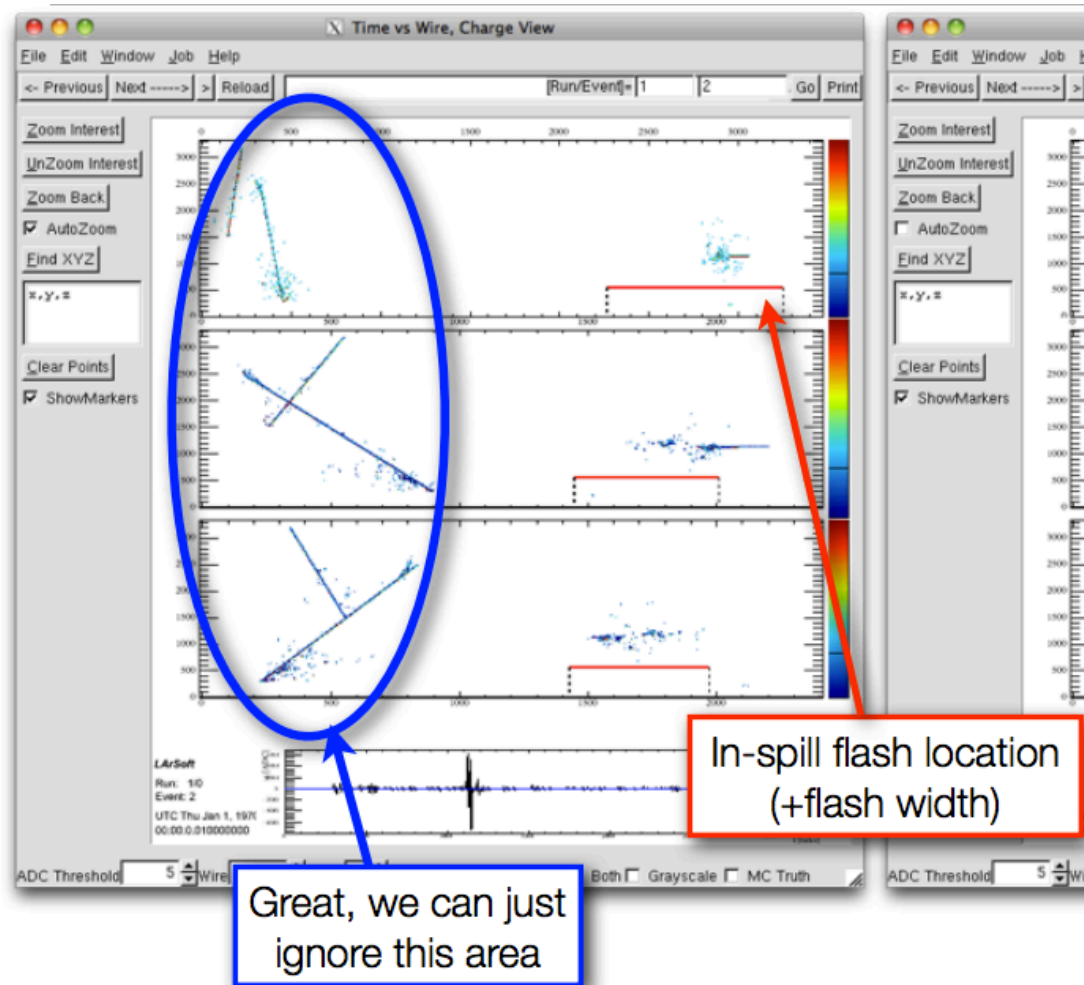
- Uses PMTs to identify subevent in time with beam (finding neutrino amidst multiple cosmics)
- **Primary goal:** Selection of real neutrino interactions amongst a large cosmic background both online (trigger) and offline (reconstruction)
- May provide info on whether to reconstruct a cosmic ray (out-of-time tracks), saving CPU time.
- Provides early to late light info for PID.



*Source: B. Jones



Flash Finder: Event Display

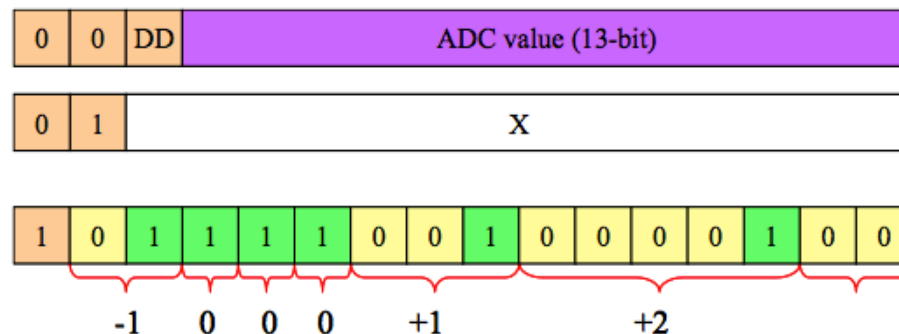


*Source: B. Jones

Huffman Coding

- Lossless data reduction: Huffman Coding
 - Successive data samples vary slowly in time.
 - Up to factor 10-15 reduction possible. Expected 8x.
- Average data volume further reduced by requiring PMT trigger in coincidence with beam gate.

$U(n+1)-U(n)$	Code
-4 and others	Full 16 bits word
-3	000001
-2	0001
-1	01
0	1
+1	001
+2	00001
+3	0000001

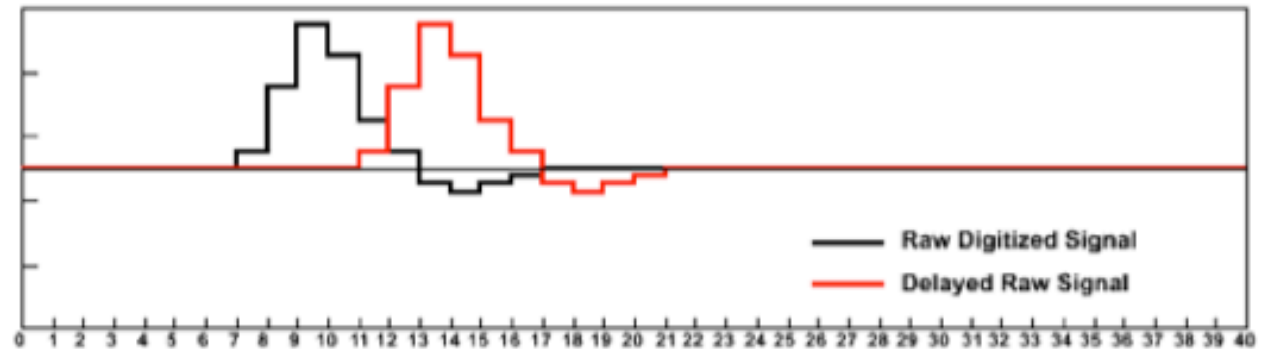


Supernova Stream

- Continuous readout with temporary data storage awaiting a SNEWS alert.
 - Stores on the order of ~a few hours.
- ~Gigabytes/sec from PMTs
- Additional “dynamic decimation” used for supernova stream
 - Not lossless. Data reduction $\sim \times(1/16)$
 - Combined with Huffman to reach required 80x data size reduction.

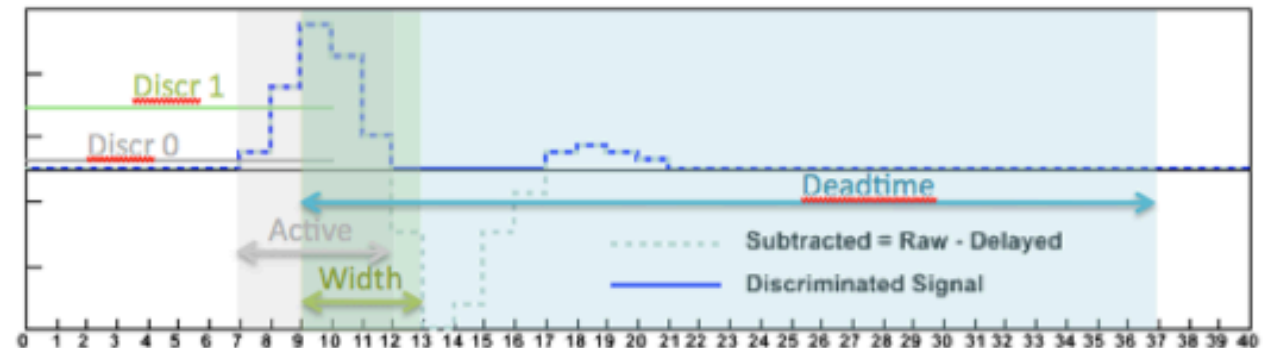
Single-channel ADC data

Same data, delayed by delay0 samples...



...and subtracted from original to form subtracted pulse. Negative values get padded to zero to for "difference".

Difference gets discriminated.



Output data:

If both Discr 0 and Discr 1 fire, a number of ADC words, N, from the raw pulse is output, along with three header words describing the frame number, channel number, and first-ADC sample number.

Relevant timing definitions:

- Discr 0 edge defines an "active" window of fixed duration, during which Discr 1 can fire.
- Discr 1 edge defines a discriminator "width" of fixed duration, during which the maximum ADC value for that particular channel is found.
- Discr 1 edge also defines a discriminator "deadtime" of fixed duration (to cover after-pulsing)



1) **Beam PMT trigger:** During any of the beam gates (BNB, NuMI, or Strobe):

High gain: Require “Beam” sum threshold $\geq 2\text{PE}$ over all tubes, and a multiplicity of ≥ 1 . The sum threshold is an active sum of peak pulse heights over 100ns using the Discr 3 level, with the Discr 3 threshold set to $\geq 1\text{ PE}$.

Notes:

This covers the possibility of 1 PMT channel with 2 PE, or 2 PMT channels with 1 PE each.

This mainly triggers on cosmics but it is efficient for neutrino-induced events.

We need to efficiently trigger on a 40 MeV proton from an NC elastic event.

2) **Cosmic PMT trigger:**

High gain: Require “Cosmic” sum threshold $> 40\text{PE}$ (or higher) in 1 (or n) tube(s) using Discr 1 level and outside of any of the four frames surrounding the beam gates.

Notes:

This provides cosmic events outside of the beam gate readouts.

It will need to be pre-scaled.



For any given subtracted pulse, **Discr 0** (timing) will fire if:

- threshold 0 is satisfied
- + the number of (64MHz) samples from the last Discr 0 firing is greater than some “precount” value (this ensures the system is in a relatively quiet state, and avoids firing on noise which reduces system efficiency)
- + threshold 0 is satisfied outside the “deadtime” of Discr 1 and Discr 3, both of which can fire after Discr 0

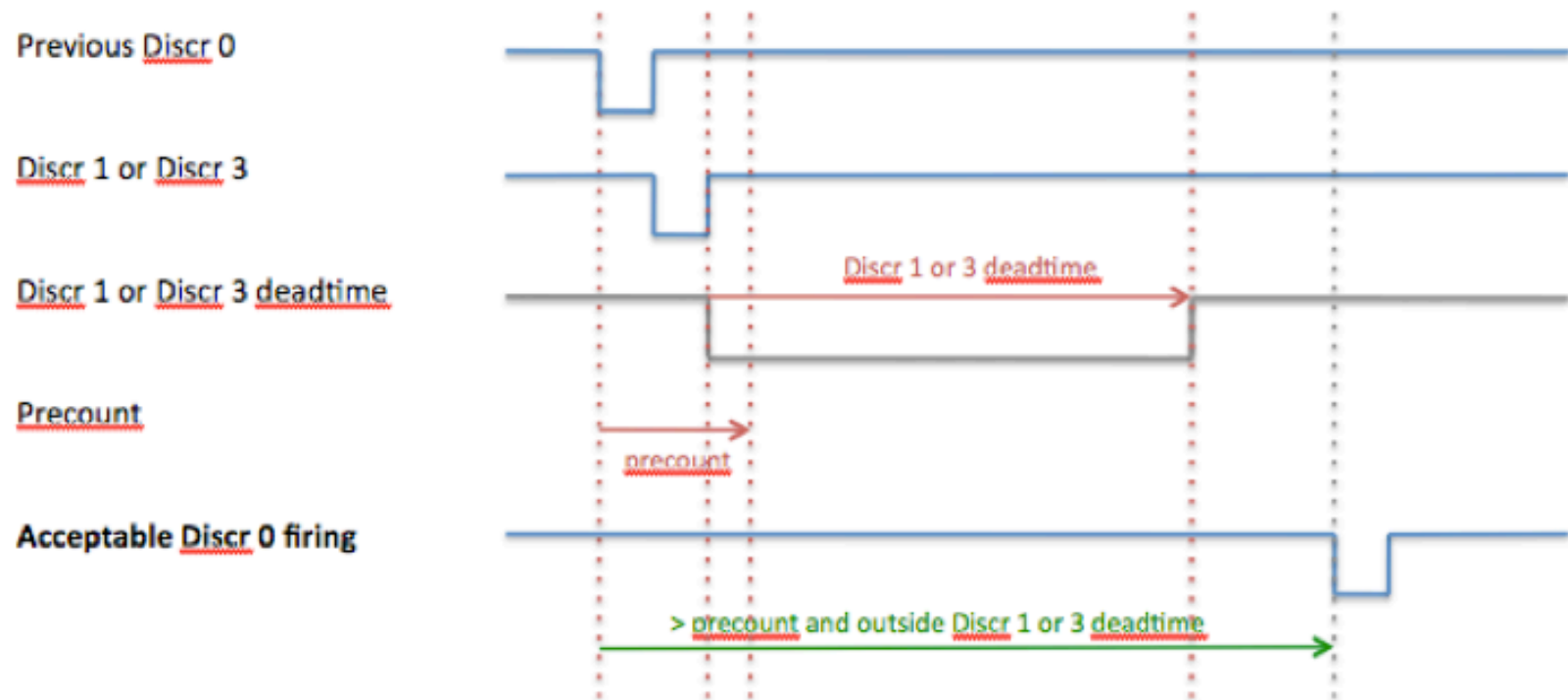


Figure 8: Discr 0 firing conditions

Discr 1 (cosmic) will fire if:

- Discr 0 has fired no more than 6-7 samples earlier (the exact number of samples is tunable at run configuration, but its value is based on the shaping time)
- + threshold 1 is satisfied
- + threshold 1 is satisfied outside the “beam window” surrounding the beam gate

Whenever Discr 1 fires, N=20 samples relative to Discr 0 firing (preceding Discr 1) will be stored in the FIFO. N is a 12-bit number, loaded at run configuration.

Discr 0

23.4 μ s window surrounding
beam gate

Acceptable Discr 1 firing

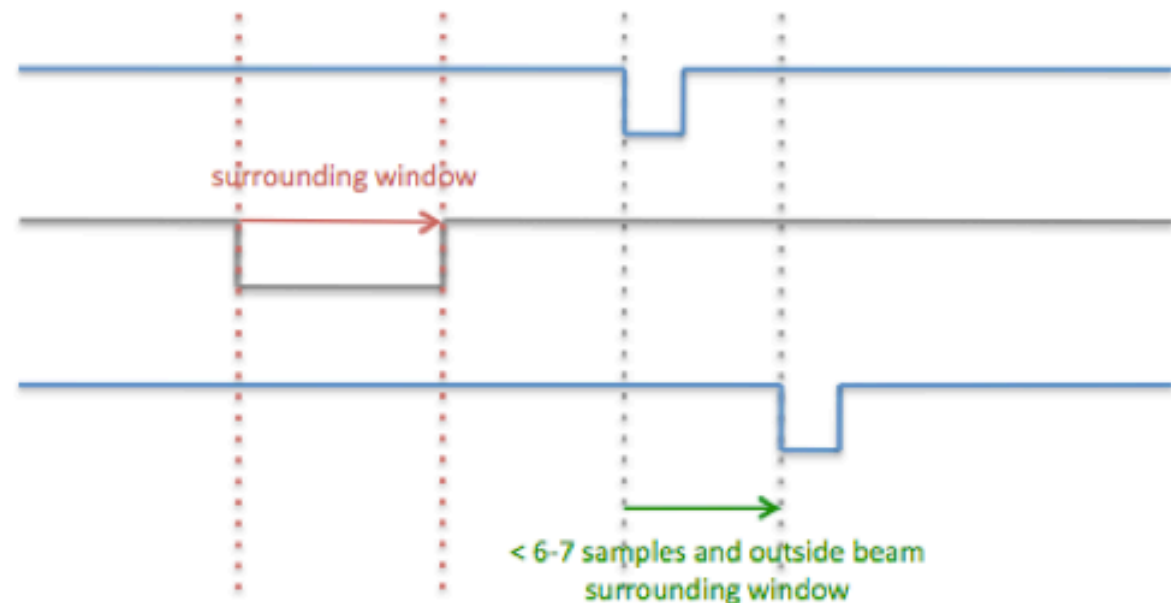
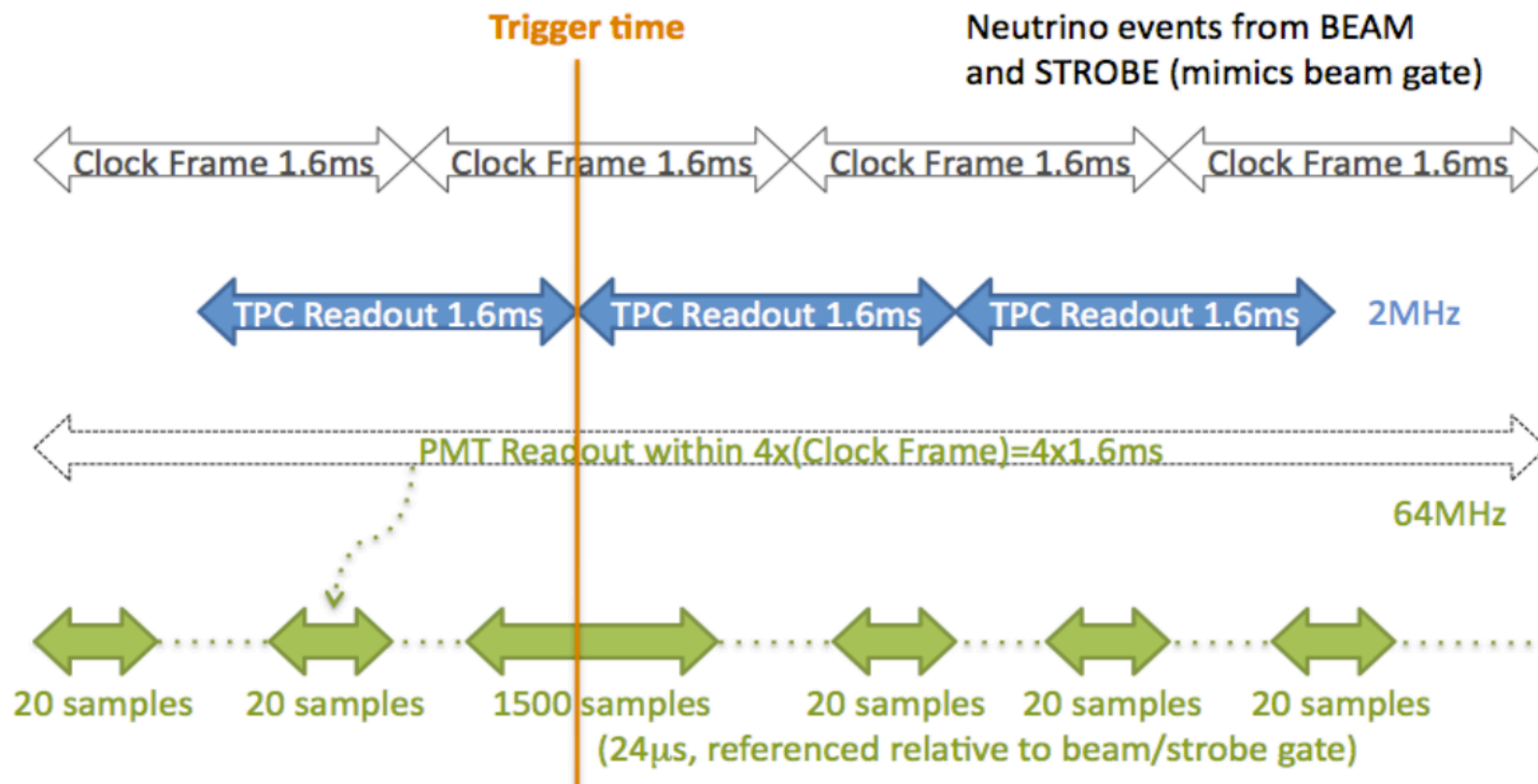


Figure 9: Discr 1 firing conditions

Supernova Stream



- Ignore the orange trigger line. All of this read out continuously and stored for ~a few hours.

Discr 3 (beam) will fire if:

- Discr 0 has fired no more than 6-7 samples earlier (the number of samples is tunable)
- + threshold 3 is satisfied
- + threshold 3 is satisfied inside the “beam gate”

Discr 0

Beam gate

Acceptable Discr 3 firing

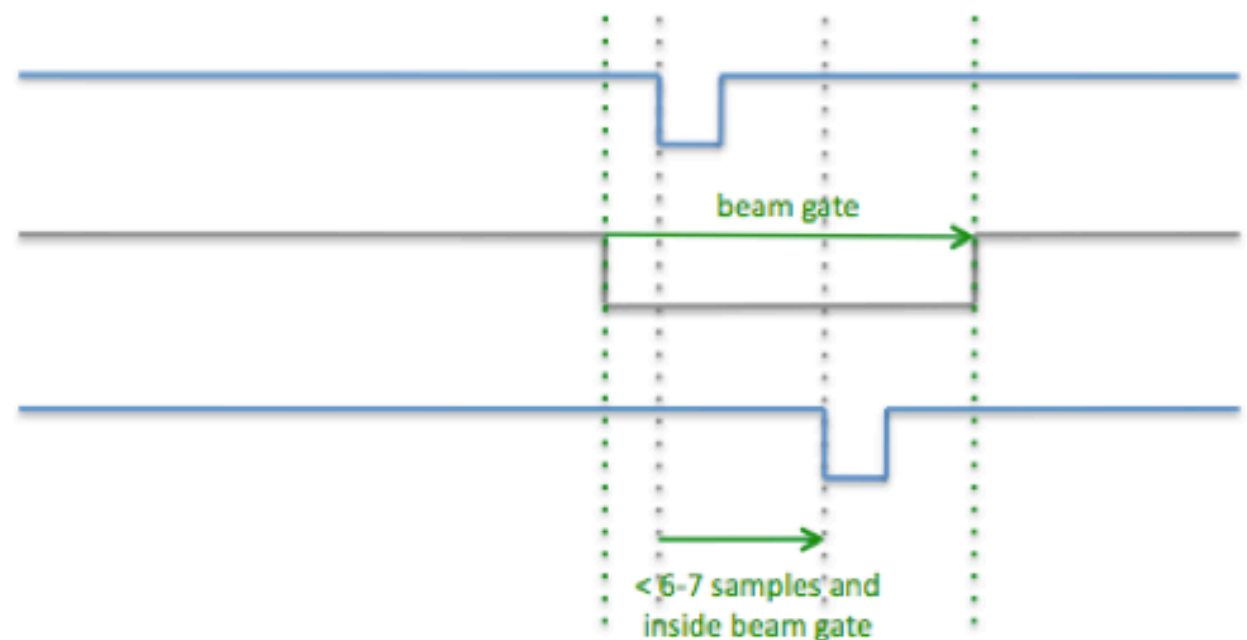


Figure 10: Discr 3 firing conditions

References outside of uB

- <http://indico.cern.ch/getFile.py/access?contribId=s2t3&sessionId=s2&resId=0&materialId=0&confId=a053785>
 - Kirill Melnikov, UHawaii. (Michel Feynman Diagram)